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Effects of killed cover crop mulch on weeds, weed seeds, and herbivores

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Abstract

The feasibility of killed cover crop mulches as an alternative to methyl bromide fumigation was investigated in spring bell pepper and fall collard production by examining post-dispersal predation on weed seed, predation on beet armyworm larvae and pupae, percent weed cover, invertebrate activity, activity of red imported fire ant, and crop yield. In three experiments, 5047 weed seeds were removed from cover crop mulch plots compared to 1860 seeds from standard production plots, and within treatments, predation increased significantly with decreasing seed size. Predation of beet armyworm pupae was 33% greater in cover crop mulch compared to conventional production plots. Fire ants were the main predator of weed seed and pest insects. In the two bell pepper experiments, weed cover per square meter was 31.8% less in standard production than in cover crop mulch plots. The mean number of invertebrates (other than fire ants) captured in pitfall traps was 5.8 ± 0.1 plot^{-1} versus 3.8 ± 0.8 plot^{-1} for cover crop and conventional treatments, respectively. There were 5734 fire ants captured in mulched cover crop plots compared to 1278 in conventional production plots. There was no significant difference in crop yield among treatments. The results suggest fire ants were more abundant where there was mulched cover and were important predators of weed seed and pest insects in killed cover crop plots and that cover crop mulches in summer pepper and fall collard production are potentially viable alternatives to black plastic mulch and soil fumigation.

Keywords: *Brassica oleracea*; *Capsicum annuum*; Killed cover crop mulch; No-tillage; *Solenopsis invicta*; *Vicia sativa*; Weed control

1. Introduction

Cover crops are used in cropping systems because they improve soil fertility and crop performance. Short-term impacts include weed and pest population control (Putnam and DeFrank, 1983; Mangan et al., 1995), positive effects on radiation balance (Facelli and Pickett, 1991), soil moisture and temperature (Bristow, 1988), and nitrogen availability (Echenkamp and Moomaw, 1989). All of these factors may enhance crop performance.

Cover crops can provide biological weed control by replacing an unmanageable weed population with a manageable cover crop species (e.g., Teasdale, 1996). Winter annual cover crops are planted in late summer or early fall, become established before winter, and have the greatest biomass by early spring, before the summer crop is planted. In most cases the cover crop is killed with herbicide or mowed before the summer crop is planted, leaving a mulch residue on the soil surface.

Mulched cover crops also may provide favorable microhabitats for beneficial insects (Orr et al., 1997; Reader, 1991; Stinner and House, 1990), including entomophagous insects and weed seed predators. Mulched cover crops increase populations of beneficial entomopho-

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gous species such as carabids, staphylinids, and spiders (Altieri et al., 1985) which can more effectively control pests.

Cover crops also can increase populations of granivores that consume weed seeds. For example, cover crops increased populations of granivorous carabid beetles (House and Alzugaray, 1989; Laub and Luna, 1992; Armstrong and McKinlay, 1997) which are important seed consumers in temperate ecosystems (Brust and House, 1988; Kjellson, 1985; Manley, 1992; Westerman et al., 2003). Weed population dynamics are strongly affected by seed mortality, and an annual seed loss of 25–50% may decrease weed population growth substantially (Firbank and Watkinson, 1986; Medd and Ridings, 1989).

The feasibility of using killed cover crop mulches on fall collard (*Brassica oleracea* L., acephala group) and spring bell pepper (*Capsicum annuum* L.) production in the southeastern United States was examined in this study. Specific research objectives were to compare cover crop mulch versus standard production using methyl bromide fumigation under plastic mulch for pepper and bare ground culture for collards in terms of (1) post-dispersal weed seed predation by invertebrate granivores, (2) predation of beet armyworm (*Spodoptera exigua* [Hübner]) larvae by invertebrates, (3) percent weed cover, (4) activity and abundance of invertebrates captured in pitfall traps, (5) activity and abundance of the red imported fire ant (*Solenopsis invicta* Buren), and (6) crop yield.

2. Methods

Using a 3 × 3 Latin Square design (Woolf, 1968), during summer 2000 the experiments were conducted at the USDA Agricultural Research Service U.S. Vegetable Laboratory (USVL), and during fall 2000 and summer 2001 experiments were conducted at Clemson University, Coastal Research and Education Center (CREC). The facilities were adjacent to one another (32°78″N, 80°05″W) in Charleston, South Carolina. Soil type in all fields was very fine sandy loam, pH 6.4.

2.1. Bell pepper and collard production

Bell pepper (cultivar 'Camelot') and collard (cultivar 'Champion') were used as the summer and fall crops, respectively. In 2000 Cahaba white vetch (*Vicia sativa* cv. Cahaba) and in 2001 a rye-vetch (*Secale cereale* L.–*V. sativa*) mixture was used as cover. The rye-vetch mix was used in 2001 because vetch alone decomposed rapidly and failed to provide sufficient cover throughout the summer 2000 growing season. Fields were planted with Cahaba vetch (1999) and rye-vetch (2000) cover in October and were 130 m long × 9 rows wide. Fields were divided into nine plots, with three treatments replicated three times. Treatments were killed cover crop mulch (*kcc*), 1.25-ml black polyethylene mulch alone (*pal*), and 1.25-ml black polyethylene mulch with methyl bromide (*pmb*). The *pmb* is the standard practice used by many fresh market bell pepper growers. Each plot was 30 m long × 3 rows wide. To increase separation among treatments, a 5 m segment of each row was left unplanted between plots.

In mid-April 2000, vetch cover was disked in *pmb* and *pal* plots. In *kcc* plots, vetch was sprayed with 0.73 l/ha glyphosate herbicide and left on the soil surface as mulch. Two weeks prior to planting, *pal* and *pmb* plots were disked and bedded on 1 m centers. Beds were 15 cm high and 0.9 m wide. Methyl bromide (95%) and 2% chloropicrin were injected at 73 kg/ha 5 cm into the soil in *pmb* plots and polyethylene mulch was installed. The three *kcc* plots were disked and bedded prior to planting vetch in October and were not disked again in the spring. In mid-April 2001, the rye-vetch was mowed rather than sprayed with herbicide. The mowed cover crop does not resprout, however, mowing deposited much of the cover crop material in the alleys between raised beds instead of on beds themselves. Rye-vetch plant material from an adjacent field was mowed and transported to the experimental field. Other treatment plots were prepared as described for summer 2000 experiments.

In early March, pepper seeds were planted in flats of autoclaved soil in the greenhouse. Seedlings were transferred to individual seedling trays on early April, and on May 15, 2000 and May 1, 2001, pepper seedlings were transplanted into double rows spaced 38 cm apart.

For collard production, velvet bean (*Mucuna pruriens* (L.) DC. var. *utilis*) was the cover crop. Experiments were conducted in field A2 of Clemson University CREC, Charleston, SC. Field size was 100 m long × 9 rows wide. Treatments were killed cover crop mulch (*kcc*), bare ground fallow (*bgf*), and bare ground with disked cover (*bgdc*), the latter being the standard practice for many collard producers.

In June the fields were disked twice and raised beds were formed. Velvet bean was seeded in *kcc* and *bgdc* plots on June 27 at 140 kg/ha in double rows spaced 0.38 m apart on 0.9 m wide beds. Velvet bean grew until August 24 when it was sprayed with 0.57 l/ha Gramoxone (SYNGENTA, Basel, Switzerland). Cover crop plots were mowed September 1, and Gramoxone was reapplied 6 days later. Velvet bean growth was inhibited in the study field by an unidentified viral disease, so velvet bean from a secondary field was mowed and transported to *bgdc* and *kcc* plots then manually spread onto raised beds to a depth of approximately 10 cm. The secondary field had been planted as a backup in case of poor cover establishment in the main field.

2.2. Weed seed and pupal predation

In 2000, predation experiments were done using four weed species common to the coastal Southeast: redroot pigweed (*Amaranthus retroflexus* L. (1–2 mm)), sicklepod (*Cassia obtusifolia* L. (2–3 mm)), morning glory (*Ipomoea* *hederacea* L. (3–5 mm)), and Johnsongrass (*Sorghum halepense* (2–3 mm)). These species represent a wide range of seed size and morphology and are all economically important pest species. In 2001, *I. hederacea* was not used because of very low predation rates the previous summer.

To compare seed predation among treatments, weed seeds (one species per cage) were placed in vertebrate exclusion cages made from 1.25 cm^2, rigid wire mesh cloth. Cages were 15 cm × 15 cm × 10 cm with lids made from the same wire mesh. Lids were covered with 2 mm plastic to protect seeds from rain. Each week, 25 seeds of each species were placed on 10 cm × 10 cm 3 M™ brown metallic finishing pads inside separate wire mesh exclusion cages (Menelled et al., 2000; Seaman and Marino, 2003). Cages were arranged in all plots systematically, beginning 7 m from the plot edge and spaced 5 m apart. Each seed type was represented once in each of three rows per plot, and there were 12 exclusion cages (4 seed species × 3 rows) in each plot. Thus, in each plot, 12 sample units (four species with three repetitions) were established using a total of 300 seeds in each trial.

Seeds were left in the field for 7 days, after which seeds and pads from each cage were collected and placed in separate Ziplock™ bags. Seeds remaining on the pads were later counted in the laboratory. On the same day seeds were collected, a new group of 25 seeds was placed in each exclusion cage. Cages were not moved throughout the experiment but seeds of different species were randomly assigned to cages each week. Seed predation experiments were conducted seven (initiated in mid-May) and six (fall 2000 collard study; initiated October 5) times throughout the growing season.

In 2001, a second set of cages (0.32 cm^2 wire mesh) was also included to exclude large (ground beetles and crickets (Orthoptera: Gryllidae)) but not small (fire ants) seed predators. Small and large mesh cages were adjacent to one another and spaced 0.5 m apart. In each plot, 18 sample units (three species, two mesh sizes, and three repetitions) were established using a total of 450 seeds per plot for each trial.

Beet armyworm pupae were used to compare predation on crop insect pests among treatments. Pupae were set out on 3 M metallic finishing pads in both 1.3 and 0.32 cm vertebrate exclusion cages. There were nine exclusion cages of each mesh size, 3 per row × 3 rows, for a total of 18 cages per plot. Cages were spaced 5 m apart on raised beds, with the first cage placed 7 m from the plot edge. Large and fine mesh exclusion cages were set adjacent to one another and 0.5 m apart. Pupae were placed in cages 10–15 min before dark and left in the field until first light the following morning. This approach was chosen because daytime levels of wasp and fire ant activity in and around the field were high. This experiment was repeated five (2000), four (2001), and three (fall 2000 collard study; initiated October 26) times throughout the growing season.

2.3. Sampling

Pitfall traps (9 cm diameter) were used to estimate insect activity and diversity in treatment plots. There were three traps in each plot, one per row, and traps were opened weekly for 24–48 h. Individuals of known taxa were quantified in the field and released to minimize insect mortality. Individuals of unknown taxa were pinned or placed in alcohol and later identified.

To estimate fire ant populations, screw-capped glass scintillation vials (20 ml) baited with a ~1 cm^2 piece of beef hot dog were used. Six vials were set out in each plot, two per row spaced 15 m apart, and vials were left in the field for 20 min. Vials were collected in the same order in which they were set out so sampling time was approximately equal. Vials were placed in the freezer for 24 h to kill ants before counting them. In 2000 peppers and collards were monitored 10 and 6 times, respectively, whereas in 2001 peppers were monitored six times during the growing season.

In 2000, percent weed cover was estimated in 6 m^2 quadrats within each treatment plot, 28 days after peppers were planted. Quadrat position was selected randomly within each plot, and percent cover of each species inside the 1 m^2 area was estimated and recorded. In 2001, percent cover of weeds was surveyed 48 and 61 days after peppers were planted. At the time of the second survey, weed biomass also was measured in the same quadrats used to estimate percent cover. All non-crop plant material was clipped and bagged. Weeds rooted within the plots were clipped at the soil surface. For weeds rooted outside the frame, only the part of the plant extending into the m^2 area was clipped and bagged. Weeds were dried at 45 °C for 10 days and then weighed.

2.4. Crop yield

In 2000, pepper yield in all plots was reduced by as much as 80% due to a widespread outbreak of tomato spotted wilt virus. In 2001, to compare pepper yield among treatments, whole plots were harvested on June 20 and again on July 9. All healthy peppers larger than 8 cm in diameter were harvested and counted, and the total mass of peppers from each plot was recorded. To compare crop yield among treatments in collards, a 3.1 m section was harvested in the four interior rows of each plot on November 20 and 22 and recorded as fresh weight.

2.5. Statistical analyses

All means reported are for untransformed variates and are expressed as mean ± S.E. unless otherwise indicated. Analyses were performed using JMP statistical software (SAS Institute Inc., Cary, NC). Alpha was 0.05 for all hypothesis testing, and after ANOVA, the Tukey–Kramer HSD method was used to determine which treatment means differed significantly from one another.

Table 1
Analysis of the mean number of seeds removed/cage/week

Source of variation	d.f.	SS	*F* ratio	Probability
a. Bell peppers summer 2000				
Treatment	2	5.4	53.9	<0.0001
Time	6	6.5	21.8	<0.0001
Treatment × time	12	2.5	4.2	<0.0001
Seed type (treatment)	9	13.9	30.9	<0.0001
Row	2	0.2	2.3	0.1035
Column	2	0.1	0.6	0.5243
Error	216	10.8		
Total	249	39.4		
b. Bell peppers summer 2001				
Treatment	2	3.9	33.2	<0.0001
Time	6	4.9	14.0	<0.0001
Treatment × time	12	3.7	5.3	<0.0001
Seed type (treatment)	6	17.8	50.5	<0.0001
Mesh size (seed type, treatment)	9	1.0	1.9	0.0530
Row	2	0.3	2.2	0.1091
Column	2	0.3	2.6	0.0734
Error	301	17.71		
Total	340	49.7		
c. Collards fall 2000				
Treatment	2	11.4	155.1	<0.0001
Time	5	1.2	6.4	<0.0001
Treatment × time	10	0.5	1.3	0.2102
Seed type (treatment)	9	14.2	42.8	<0.0001
Row	2	0.1	1.8	0.1654
Column	2	0.1	0.8	0.4541
Error	184	6.78		
Total	214	34.3		

The nested effects of seed type within treatment and mesh size within seed type within treatment were fixed effects, therefore the residual error was used to generate *F*-statistics for hypothesis testing.

Data were $\log_{10}(x + 1)$ transformed to better approximate ANOVA assumptions, especially normality and homoscedasticity. For summer 2000, effects in the model were treatment, seed type nested within treatment, time, and Latin row and column. Because uneaten seeds were collected and new seeds were put out each week, the time × treatment interaction terms were also tested. For summer 2001, the nested effect of mesh size within seed type within treatment was added to the model. Because all nested effects in the model were fixed and not random, the residual mean square was used to calculate all *F*-statistics for hypothesis testing (Zar, 1999).

Repeated measures ANOVA was used to compare pupae predation over time, among treatments, and between large and small mesh exclusion cages within treatments. Row and column effects were also included. The response variable in the model was percent pupae predation.

For fall 2000 and summer 2001, ANOVA was used to compare yield (number of marketable collards and peppers harvested per plot, respectively) among treatments. Model effects were treatment, Latin row, and Latin column. Analysis of variance was used to compare the number of fire ants captured in treatment plots and the abundance of ground dwelling insects over time. Data on fire ants were $\log_{10}(x + 1)$ transformed to better approximate ANOVA assumptions. Effects in the model were treatment, time, treatment × time interaction, Latin row, and Latin column. Analysis of variance was used to compare percent weed cover per square meter among treatments. Variates were $\log_{10}(x + 1)$ transformed to better meet ANOVA assumptions. For summer 2001, sampling date was included in the model because percent weed cover was estimated twice during of the growing season. Weed biomass was expressed as mean dry weight per square meter.

3. Results

3.1. Bell peppers

In both years, treatments significantly affected seed predation (Table 1). The mean number of seeds removed per cage was significantly greater in *kcc* compared to *pal* and

Table 2
Comparison of seed and insect predation, weed cover, fire ant abundance, and crop yield for bell peppers and collard

Treatment	Seed predation (mean no. removed/cage)	Pupal predation (mean% of cages having predation)	Percent weed cover (%weed cover/m^2)	Fire ants (mean no. captured/plot)	Vegetable yield (mean no./plot)
a. Bell peppers summer 2000					
Killed cover crop	7.4 ± 0.5a	68.9 ± 5.6a	58.0 ± 5.5a	168.5 ± 48.5a	–
Plastic alone	3.3 ± 0.3b	52.7 ± 5.5b	22.2 ± 4.1b	42.7 ± 16.4b	–
Plastic + methyl bromide	3.1 ± 0.3b	35.1 ± 6.2b	6.2 ± 1.1c	37.4 ± 14.1b	–
b. Bell peppers summer 2001					
Killed cover crop	5.2 ± 0.5a	72.9 ± 4.8a	18.6 ± 3.5a	109.5 ± 32.0a	523.0 ± 169a
Plastic alone	2.2 ± 0.3b	40.3 ± 5.4b	26.0 ± 3.2a	34.5 ± 12.4b	515.0 ± 86a
Plastic + methyl bromide	2.2 ± 0.3b	50.0 ± 6.5b	6.8 ± 1.8b	23.3 ± 8.1b	620.6 ± 114a
c. Collards fall 2000					
Killed cover crop	8.0 ± 0.7a	88.9 ± 3.1a	–	–	7.5 ± (0.63)a
Bare ground fallow	2.3 ± 0.4b	51.4 ± 6.3b	–	–	9.2 ± (0.51)a
Bare ground/disked cover	2.1 ± 0.3b	47.2 ± 11.0b	–	–	9.1 ± (0.55)a

Table values are untransformed means ± S.E., except for collard yield. For collards, yield is expressed as the mean number of plants per 3.1 linear m with mean mass (kg) per plant in parentheses. Values with a different letter are statistically different (Tukey–Kramer HSD test).

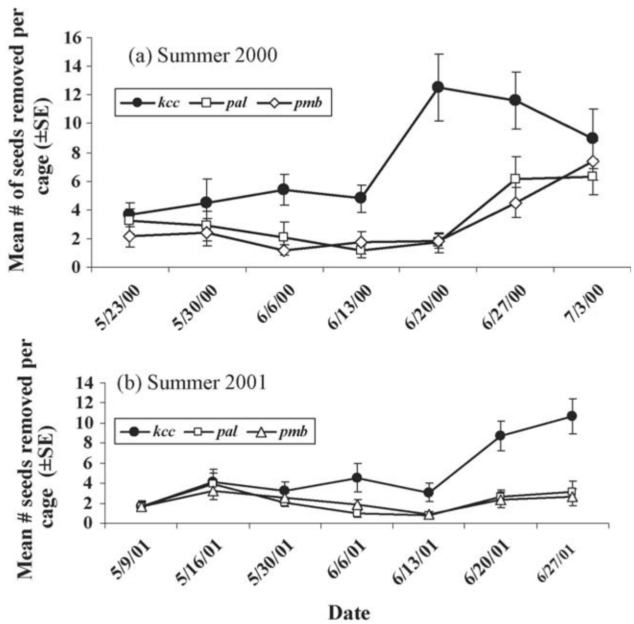

Fig. 1. Change in weed seed predation over time during (a) summer 2000 and (b) summer 2001 bell pepper study. *kcc*: killed Cahaba vetch cover, *pal*: plastic alone, and *pmb*: plastic with methyl bromide fumigation.

pmb plots (Table 2), while *pmb* and *pal* plots were not statistically distinguishable. The total number of seeds removed from *kcc* plots (2000: 1777; 2001: 1656) was greater than the number of seeds removed from *pal* and *pmb* plots combined (2000: 1487; 2001: 1424).

In both years, the nested effect of seed type within treatment also significantly affected seed predation (Table 1). In all treatments, the number of seeds removed was highest on seeds of *A. retroflexus* (2000: 8.8 ± 1.0; 2001: 6.2 ± 0.74), followed by *S. halepense* (2000: 5.7 ± 1.1; 2001: 2.1 ± 0.26), *C. obtusifolia* (2000: 2.6 ± 0.6; 2001: 1.2 ± 0.31), then *I. hederacea* (2000: 1.5 ± 0.3). Time and treatment $\times$ time interactions significantly affected weed seed predation (Table 1). Seed removal in all treatments increased during the experiment, especially in *kcc plots* (Fig. 1a and b). Exclusion cage mesh size did not significantly affect granivory.

In both years, treatments, but not mesh size, significantly affected percent predation on beet armyworm pupae (Table 3), which was significantly higher in *kcc* versus *pal* and *pmb* plots (Table 2) while *pal* and *pmb* plots were statistically indistinguishable. In 2000, percent predation varied significantly among surveys (Fig. 2) and in 2001 there was significant spatial variation in percent pupae predation among columns (Table 3). Mean percent pupae predation was significantly greater among plots within column I (66.0 ± 5.8) compared to column III (43.8 ± 6.1).

In both years, treatment significantly affected percent weed cover and in 2001 mean percent weed cover varied significantly in all treatments between sampling dates (Table 4). In 2000, percent weed cover per square meter was greater in *kcc* compared to *pal* and *pmb* treatment plots whereas in 2001 percent weed cover per square meter was greater in *kcc* and *pal* plots compared to *pmb*. Weed cover was higher in *pal* than *pmb* plots in 2000 whereas *kcc* and *pal* plots in 2001 were statistically indistinguishable (Table 2). In 2000, there was significant spatial variation in weed coverage (Table 4); plots in row II had significantly greater percent weed coverage (37.2 ± 8.6) compared to plots in rows I (23.0 ± 9.0) and III (26.3 ± 6.4) and in 2001 weed biomass (dry weight, g) per square meter was greatest in *pal* (82.1 ± 15.2) followed by *kcc* (49.2 ± 11.2) and *pmb* (28.2 ± 10.6). The most commonly observed weeds in both years were eclipta (*Eclipta alba* [L.] Hassk.), green carpetweed (*Mollugo verticillata* L.), redroot pigweed (*A. retroflexus* L.), and common purslane (*Portulaca oleracea* L.). In 2000 purple nutsedge (*Cyperus rotundus* L.) and in 2001 spiny amaranth (*Amaranthus*

Table 3
Analysis of the percentage of cages having pupal

Source of variation	d.f.	SS	*F* ratio	Probability
a. Bell peppers summer 2000				
Treatment	2	7599.7	4.83	0.0110
Time	4	44508.7	14.14	<0.0001
Mesh size (treatment)	3	5787.2	2.45	0.0709
Row	2	2751.3	1.75	0.1819
Column	2	1315.1	0.84	0.4381
Error	68	53525.5		
Total	81	115487.5		
b. Bell peppers summer 2001				
Treatment	2	13479.9	13.48	<0.0001
Time	3	3530.1	2.35	0.0001
Mesh size (treatment)	3	12233.8	8.15	0.0813
Row	2	841.0	0.84	0.4365
Column	2	5956.8	5.95	0.0044
Error	59	29510.0		
Total	71	65551.7		
c. Collards fall 2000				
Treatment	2	12632.2	11.71	0.0003
Time	2	1313.3	1.22	0.3136
Mesh size (treatment)	3	1771.4	1.09	0.3705
Row	2	553.9	0.51	0.6049
Column	2	4302.5	3.99	0.0320
Error	24	12945.5		
Total	35			

The nested effect of mesh size within treatment was a fixed effect and therefore the error mean square was used to generate *F*-statistics for hypothesis testing.

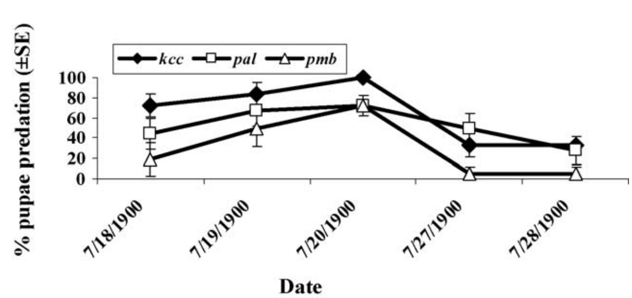

Fig. 2. Predation of beet armyworm pupae during summer 2000 bell pepper study. *kcc*: killed Cahaba vetch cover, *pal*: plastic alone, and *pmb*: plastic with methyl bromide fumigation.

Table 4
Analysis of percent weed cover/m^2 in bell pepper production plots

Source of variation	d.f.	SS	*F* ratio	Probability
a. Bell peppers summer 2000				
Treatment	2	8.38	82.51	<0.0001
Row	2	0.64	6.27	0.0038
Column	2	0.31	3.04	0.0575
Error	47	2.39		
Total	53	11.7		
b. Bell peppers summer 2001				
Treatment	2	10.31	21.43	<0.0001
Row	2	1.31	2.75	0.0690
Column	2	1.29	2.71	0.0715
Date	1	1.77	7.43	0.0076
Error	100			
Total	107			

Data were conducted once during summer 2000 and twice during summer 2001.

spinosus L.), common lambsquarters (*Chenopodium album* L.), dayflower (*Commelina communis* L.), and yellow nutsedge (*Cyperus esculentus* L.) were also commonly observed.

In 2000, but not in 2001, treatments significantly affected the number of invertebrates captured in each plot ($F_{2,41} = 5.5$, $p = 0.0078$). The mean number of invertebrates captured in pitfall traps in 2000 was greatest in *kcc* (5.7 ± 0.08) followed by *pmb* (3.8 ± 0.78) and *pal* (1.9 ± 0.78) plots.

In both years, treatment significantly affected the mean number of fire ants captured per plot (Table 5). Significantly more fire ants were captured per survey in *kcc* plots compared to *pal* and *pmb* plots (Table 2), while *pal* and *pmb* plots were statistically indistinguishable. In 2001, there was also significant spatial variation in the number of ants captured as plots in column II (plots two, five, and eight) had fewer ants than plots in columns I and III (Table 5).

In 2001, there was no significant difference among treatments in pepper yield (Table 2). Most peppers harvested from *kcc* plots were picked during the second harvest (260 versus 796 peppers per plot at first and second harvest, respectively). Similar increases in yield were not observed between first (June 20, 2001) and second (July 9, 2001) harvests in the *pmb* (566 versus 654 peppers per plot) or *pal* (545 versus 484 peppers per plot) treatments.

Table 5
Analysis of the number of ants captured/plot

Source of variation	d.f.	SS	*F* ratio	Probability
a. Bell peppers summer 2000				
Treatment	2	7.4	8.07	0.0012
Survey	6	18.2	6.65	<0.0001
Treatment × survey	12	15.0	2.75	0.0087
Row	2	1.3	1.40	0.2594
Column	2	0.7	0.78	0.4662
Error	38	17.3		
Total	62	59.9		
b. Bell peppers summer 2001				
Treatment	2	3.7	7.22	0.0022
Survey	6	8.9	5.82	0.0002
Treatment × survey	12	7.2	2.37	0.0218
Row	2	4.2	8.33	0.0010
Column	2	0.9	1.83	0.1744
Error	38	9.7		
Total	62	34.6		

3.2. Collards

Treatments significantly affected seed predation (Table 1). Mean seed predation per cage was significantly greater in *kcc* compared to *bgdc* and *bgf* treatment plots (Table 2), while *bgdc* and *bgf* plots were statistically indistinguishable. The sum of seeds removed from *kcc* (1614) plots was greater than *bgf* and *bgdc* (921) plots combined (Fig. 3).

The effect of seed type within treatment was highly significant (Table 1). Overall, predation was highest for *A. retroflexus* (9.2 ± 0.76) followed by *S. halepense* (3.9 ± 0.70), *C. obtusifolia* (2.7 ± 0.35), and *I. hederacea* (1.2 ± 0.28). Predation varied significantly over time (Fig. 3).

Pupae predation varied significantly with treatment (Table 3) and plot location ($F_{2,24} = 4.0$, $p = 0.032$). Percent predation was significantly greater in *kcc* compared to *bgdc* and *bgf* plots (Table 2). Spatially, predation was greatest among plots in column I (77.7 ± 4.7) compared to columns II (52.8 ± 10.6) and III (56.9 ± 9.9).

The number of invertebrates captured in pitfall traps did not vary significantly among treatments. Invertebrate abundance varied significantly among columns ($F_{2,32} = 6.7$; $p = 0.0037$). Significantly more invertebrates were captured in plots located in column I (12.9 ± 3.7) compared to columns II (7.2 ± 1.6) and III (7.8 ± 1.5). Mean number of invertebrates captured varied significantly over time ($F_{2,32} = 3.9$; $p = 0.0079$) ranging from 5.3 per plot on October 6 to 13.7 per plot on October 19.

Weeds were controlled at the beginning of the experiment and were not competitive after collards established. There were not enough weeds to compare percent cover among treatments.

Collard yield, expressed as fresh weight (kg) per 3.1 linear m, did not differ significantly among treatments. Although numbers of marketable-sized collard plants per

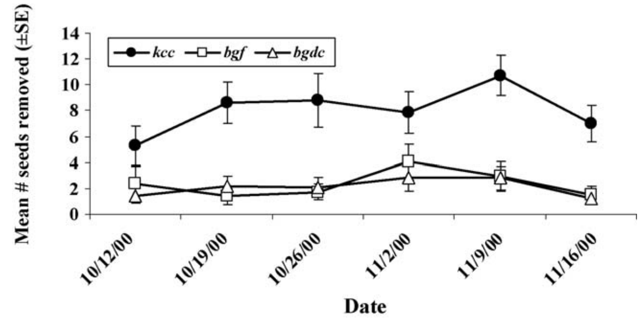

Fig. 3. Mean seed removal per cage during fall 2000 collard study. *kcc*: killed velvet bean cover, *bgf*: bare ground fallow, and *bgdc*: bare ground with disked velvet bean cover.

3.1 linear m were lower in the cover crop mulch treatment (7.5 plants) than in the disked (9.2 plants) or fallow (9.1 plants) treatments, per plant weight in *kcc* plots was almost 0.1 kg (or 16%) greater than in the other two treatments.

4. Discussion

A layer of mulched cover crop on the soil surface increased weed seed and pupal predation in pepper and collard production systems in all experiments and fire ants appeared to be the main predators. Unlike previous studies that suggested carabid beetles were important consumers of weed seeds in agroecosystems (Brust and House, 1988; Westerman et al., 2003), the results of this study suggest fire ants were the primary weed seed predators. Several studies have also demonstrated that fire ants can be ecologically and economically important insect predators in a variety of cropping systems (Morrill, 1977).

Susceptibility to predation differed among weed species. Predation was highest on *A. retroflexus*, which had the smallest seeds. Fire ants are selective seed predators that prefer seeds of *A. retroflexus* (Seaman and Marino, 2003). Predation was lowest on *I. hederacea*, which had the largest seeds.

Post-dispersal predation of weed seeds is common in agricultural systems (e.g., Manley, 1992; Cardina et al., 1996; Marino et al., 1997; Menelled et al., 2000) and weed population dynamics are strongly affected by seed mortality (Firbank and Watkinson, 1986; Medd and Ridings, 1989). Fire ant predation on weed seeds, which is enhanced under a killed mulch system, may affect weed population dynamics.

Fire ants may have been more abundant in *kcc* plots compared to other treatment plots during both summer experiments due in part to early season ant mortality from methyl bromide fumigation in *pmb* plots. In addition, the polyethylene or black plastic mulch used in *pal* and *pmb* treatment plots may have acted as a mechanical barrier to mound building by ants. Mounds only occurred in plastic mulch where the plastic had been accidentally torn or in holes made where seedlings were planted. Fire ants mainly forage using extensive tunnel networks 2–11 cm below the soil surface (Markin et al., 1975), and it may have been easier for ants to forage and build mounds in organic mulch versus black plastic. Ants also may have been more abundant in mulched cover because there were more invertebrate prey organisms there. Previous studies (Carmona and Landis, 1999; House and Alzugaray, 1989; Altieri et al., 1985) showed ground beetles and other potential invertebrate prey items were more abundant in plots with cover crops and/or reduced tillage compared to clean cultivated plots.

Spatial variation in ant abundance during summer 2001 could have been related to excessive moisture in some plots. In all treatment plots ant mounds were only observed on raised beds used for planting and never in the alleys between beds. Fire ants tend to build mounds above ground to raise the colony above the water table in saturated ground and raised beds may be preferred colonization sites. Field drainage and infiltration were poor in several areas within the study site.

Although weed seed predation was highest in mulched plots, weed density and biomass were lower with methyl bromide fumigation than with killed cover crop mulch or plastic alone. On the other hand, the results of this study suggest that the use of killed mulch has promise in these production systems as it did not decrease pepper or collard yield. The rye-hairy vetch mulch (summer 2001) was 48% more effective in reducing weed cover than Cahaba vetch alone (summer 2000). In addition, rye-vetch mulch suppressed weeds as well as plastic mulch alone in summer 2001, and weed biomass was significantly lower under killed cover crop mulch compared to plastic alone. Although not as effective as methyl bromide fumigation, killed cover crop mulch can be an effective weed control mechanism given a suitable cover and sufficient mulch biomass. Winter rye is allelopathic (Barnes and Putnam, 1983) and inhibits germination and growth of certain weed species by leaching phytotoxic compounds (White et al., 1990; Putnam, 1990).

There are costs associated with all cover crops. Mulches can effect crop development. In this study, harvestable peppers developed slower in organic mulch versus conventional production plots where 75% of peppers were picked at the second harvest. Black polyethylene mulch accelerates fruit maturity by warming the soil and promoting plant growth early in the season (Abdul-Baki et al., 1992; Bhella, 1988). In contrast, cover crop mulch delayed tomato maturity by approximately 10 days relative to black plastic mulch, and plants in the cover crop mulch treatment had higher yields than those grown under black plastic (Abdul-Baki and Teasdale, 1993). Other costs include increased activity by nematodes (Powell, 1990) and fungal pathogens (Sumner et al., 1995; Schroeder et al., 1998; Keinath et al., 2003), difficulties effectively growing and killing the cover (Creamer et al., 1995) and, for example, in this study greater pepper mortality from cutworm damage (plants killed: *kcc* = 147; *pal* = 30; *pmb* = 7).

Difficulty in establishing an adequate cover was a problem in all experimental fields. In fall 2000, an unknown viral pathogen greatly reduced velvet bean establishment and growth, making it necessary to manually transfer mowed plant material from a backup field to the raised beds in the study plots. In summer 2001, mowing of the rye-vetch mixed cover resulted in most plant material being spread into alleys between raised beds instead of on beds themselves. Clearly, future studies should examine which species to use for cover crops and how to effectively grow and kill cover crops (see Creamer et al., 1995) in the southeastern United States. Cost savings and increased sustainability realized from reduced tillage and discontinued use of soil fumigants and plastic mulches may far outweigh the negative impacts associated with cover crop mulches in summer pepper production thereby making them a potentially economically viable alternative to soil fumigation using methyl bromide.

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